Solar Storm GIC Forecasting: Solar Shield Extension - GIC Forecasting System Requirements

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Abstract

A NASA Goddard Space Flight Center Heliophysics Science Division-lead team that includes NOAA Space Weather Prediction Center, Electric Power Research Institute, and Electric Research and Management, Inc. participants has recently partnered with the Department of Homeland Security Science and Technology Directorate to better understand the impact of Geomagnetically Induced Current (GIC) on the electric power industry. As a part of the process to improve resiliency of the system, better understanding of the power industry user requirements is needed. The ultimate goal in our work is to improve forecasting capability that will support operational decisions about proactive GIC mitigation actions. This report is based on communications with representatives of the US electric power transmission industry and documents the findings as part of the team's requirements development work.

Table of Contents

1. Introduction

A NASA Goddard Space Flight Center (GSFC) Heliophysics Science Division-lead team that includes NOAA Space Weather Prediction Center, Electric Power Research Institute (EPRI) and Electric Research and Management, Inc. (ERM) participants has recently partnered with the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) to better understand the impact of Geomagnetically Induced Current (GIC) on the electric power industry. NASA GSFC, initially working with EPRI and ERM, developed a Solar Shield system to predict the GICs. The present focus is to extend the Solar Shield system project to enhance the forecast capability (for a description of the "old" system, see *Pulkkinen et al*., 2008; 2009a, 2009b, 2010). We call the new activity as Solar Storm GIC Forecasting: Solar Shield Extension[1]. As a part of the process to enhance system reliability, the team worked to improve understanding of the power industry user requirements with emphasis on improving the forecasting system to better support operational decisions about proactive GIC mitigation actions. The GIC forecasting system requirements were developed and measured against this end goal. This report documents the findings from our requirements development work.

As the requirements development work was tied to the new GIC forecasting project, some of the terminology used in this report reflects the original Solar Shield project vocabulary. For example, long lead-time (1-2 day) GIC forecasts are referred to as Level 1 forecasts and short lead-time (15-45 minutes) forecasts are referred to as Level 2 forecasts. However, despite some of this Solar Shield terminology, the forecasting system requirements should be understood as applying to any GIC forecasting system.

The structure of this document is as follows. In Section 2, we will explain the process we used to gather the requirements. Section 3 documents the results. In Section 4, we provide a brief discussion and describe the features of a GIC forecasting system based on our understanding of the user requirements.

[1] The terms "Solar Storm GIC Forecasting: Solar Shield Extension" and "Solar Shield" are used interchangeably in this document.

2. Process for capturing the requirements

We used a two-step process for capturing the GIC forecasting system requirements. First, the Solar Shield team prepared draft requirements based on our earlier experience and initial requirements work carried out by *Pulkkinen et al.* (2008). Importantly, the draft requirements took into account what, based on current and near future capabilities, can realistically be expected from any GIC forecasting system. The draft requirements and questions were documented in a Google Forms questionnaire (see Appendix), which was sent out to industry representatives. Once the industry representatives had filled out the questionnaire, we arranged an audio conference to review the findings, go through follow-up questions and to have free-form discussion with the participants. This document was prepared based on the information gathered via the questionnaire and the follow-up audio conference.

We solicited information and feedback from the entities in the US power transmission industry that have extensive earlier experience on the GIC issue. We approached individuals that had substantial earlier observational and modeling experience in addressing GIC and who already have active mitigation procedures in place for protecting their systems from geomagnetic storm events. The industry representatives that provided the information in this report are E. Bernabeu (Dominion Virginia Power), K. Fleischer (NextEra Energy Resources), F. Koza (PJM), Q. Qiu (American Electric Power) and R. Horton (Southern Company). It is noted that due to ongoing research and development on this topic, we expect modifications to this report will be needed as more and more operators join the "GIC advanced" group allowing wider industry contribution.

3. Requirements

The requirements section is composed of three parts: general requirements, level 2 specific requirements, and other considerations. Each part constituted a separate section in the questionnaire that was used as the primary tool for information gathering (see Appendix). We note that the level 2 section was specifically targeted for the ongoing DHS S&T sponsored extended Solar Shield work.

Before discussing these three sections we provide some general background discussion about GIC forecasting. Note that these background issues were also discussed with industry representatives and FEMA during our interactions.

One frequent topic of discussion is whether scientists and engineers should be using *Kp*-index, geoelectric field or GIC in their analyses. The *Kp*-index in particular is somewhat old-fashioned and its usage in GIC analyses has often been criticized. However, it became clear through our forecasting system requirements gathering process that while *Kp*-index does not have a direct connection to GIC at individual locations and single *Kp* level can correspond to a wide variety of peak GIC magnitudes, the index is still useful for the industry. More specifically, the index can be used for classifying events as small/medium/large (more discussion on this below) and the index has been "calibrated" over the years in an operational environment to corresponding overall level of GIC. Consequently, some operators are using the *Kp*-index for safe posturing as well as for general situational awareness and do not see an urgent need to move away from using the index.

On the other hand, the primary physical quantity driving GIC is the horizontal geoelectric field on the surface of the Earth. The geoelectric field that incorporates information both about space environment and local geological conditions has been the main parameter of study in recent interactions between the space science and engineering communities (e.g., *NERC*, 2013). If a utility has a DC model of the power grid, the geoelectric field allows computations of GIC flows throughout the system. In this sense, the geoelectric field is a good, and in some cases the optimal, quantity to predict if the utility has means to translate the field into GIC.

In the Solar Shield project, we use an empirical approach to tailor the forecasting system for specific locations by utilizing the observed geomagnetic field variations and observed GIC. The tailoring automatically builds the local transmission system DC parameters and the local geological conditions into the model. Thus the forecasting system is optimized to forecast GIC directly from input magnetic field variations. GIC observations are typically obtained from the transformer neutral and provide a direct validation of the forecasts. The drawback of this approach is that if the transmission system configuration changes substantially, an updated model needs to be derived from a new set of observations. Indeed, in words of one industry representative: “For our system, predicting the local geoelectric field would be most beneficial. Because of constant changes in system topology, it would not be possible for NASA (or others) to maintain an up-to-date model of the system.” However, since Solar Shield is designed to provide GIC directly, we will focus primarily on GIC instead of geoelectric field as the main parameter of interest in this document. Most of the considerations in this document apply both to GIC and the geoelectric field.

It should be noted that most operators with GIC experience monitor DC currents at one or more locations in their system. This is the case for all of the industry representatives that participated in the preparation of this document (see Section 2). As the actual observed GIC provides the ultimate ground truth, many operators use their own monitoring to trigger mitigation actions. In this case other information, such as forecasting, is used mostly for situational awareness purposes and not necessarily to trigger actions. Further, while many of the US utilities do not currently monitor GIC, it is likely that DC neutral current observations will be commonplace once the new FERC geomagnetic disturbance regulations are in place. This means that forecast information will continue playing a supporting role and that the tailoring approach we have used in the Solar Shield project can be applied to large parts of the US bulk-power system in the future.

3.1 General requirements

In this section the text in italic are the draft requirements and the text immediately below are the industry representative reactions on the requirement.

Requirement: The GIC forecasting system should be able to give advance warnings at two different levels: Level 1 warnings providing lead-time of 15-48 hours and Level 2 warnings providing lead-time of 15-45 minutes. Level 1 warnings are based on remote sensing information about solar activity whereas Level 2 warnings are based on in situ Lagrange point 1 observations.

All industry representatives agreed that the requirement is appropriate. It was also pointed out that the system should be able to indicate if the observed solar event (i.e. requirement pertaining to Level 1 component of the forecasting system) will possibly miss the Earth.

Multiple industry representatives indicated that especially the long lead-time Level 1 forecasts are of great value. Level 2, while still useful, has reduced value due to the relatively short lead-time it can provide. In words of one industry representative: “Level 1 warnings of high accuracy and best estimate range of severity are important for safe posturing and mitigation preparation. In practical terms, it allows an operating facility (e.g., Generating Facility (GO) or Substation (TO)) to pull out their GMD mitigation procedure and stage equipment and resources prior to an event. A real advantage to Level 1 is that if the storm is anticipated to occur over a weekend or Holiday period, the safe-posturing and advance preparations (e.g., connecting a DC-Hall Effect clamp on ammeter to the generator step up (GSU) neutral before staff leaves on Friday. Then we don't have to rely on callouts to hook up and enable monitoring systems. For Level 2: These are critical for "Procedure Entry" so that active monitoring can be performed.”

Requirement: The system should be able to predict the start time of the GIC activity. Start times are given separately for Level 1 and Level 2 forecasts.

All industry representatives agreed that the requirement is appropriate.

Requirement: The system should be able to predict the intensity of the GIC activity. Intensities are given separately for Level 1 and Level 2 forecasts.

All industry representatives agreed that the requirement is appropriate. However, the definition of the term "intensity" and granularity of the forecast needs to be considered carefully. The industry representatives indicated that it is actually not necessary to attempt providing very fine granularity for the forecasts. It is more important to give indication if the event will be small/medium/large in terms of peak GIC. In words of one industry representative: "This [requirement] is important to some extent. Yes, it is good to know we are either in for a large storm or a very extreme storm. However, our procedures, monitoring, actions, etc. are designed for *Kp*-6 through *Kp*-9. In other words, space weather forecasts tell us when to enter our procedures based on predefined trigger level. Once we've entered, we measure GSU transformer neutral current and monitor against GIC rating curves. It doesn't matter if the storm intensity forecast is accurate, as we monitor directly the GIC flow on our transformers and have pre-defined actions. Intensity levels would be good for Senior Management communications and notifications." The detailed definition small/medium/large is dependent on individual transmission system operators and cannot be assigned universally. For one operator that participated the requirements discussions, "small" is an event having observed GIC of 30-90 amperes in the transformer neutral, 90-250 A "medium" and above 250 A "large." All these levels have different operator actions associated with them.

Requirement: The system should be able to indicate the geographic regions or locations affected by the GIC activity. Affected geographic regions are given separately for Level 1 and Level 2 forecasts.

All industry representatives agreed that the requirement is appropriate.

Requirement: The system should be able to predict the end of the GIC activity. End times are given separately for Level 1 and Level 2 forecasts.

All industry representatives agreed that the requirement is appropriate.

Requirement: The system should be able to give uncertainty of the prediction. Uncertainties are given separately for Level 1 and Level 2 forecasts.

All industry representatives agreed that the requirement is appropriate. However, for practical application the uncertainty should not be too large. In words of one industry representative: "Uncertainty is always good to have as long as the error bars are not too big. Being within +/- 15-20% is acceptable."

Requirement: The system should be able to give the prediction of the GIC activity in a form usable for the decision-making process associated with possible GIC mitigation actions.

All industry representatives agreed that the requirement is appropriate. The system should give indication of expected peak GIC levels at locations of interest. It was indicated that the concept of "usable for decision-making" is linked to the accuracy of the forecast. In words of one industry representative: "If it [forecast] has been proven to be reliable enough to be trusted, we can incorporate the forecast information in our decision-making process, otherwise, we will have to depend on our GIC/Harmonics monitoring system to take actions." In addition to GIC prediction, some of the representatives pointed out that geoelectric field predictions could also be useful and advantageous for their application.

3.2 Level 2 specific requirements

In this section the text in italic are the draft requirements and the text immediately below are the industry representative reactions on the requirement.

Requirement: Level 2 part of the forecasting system should be able to predict GIC with 10 Amp granularity and accuracy. In other words, the Level 2 system should be able to predict if the GIC will be 10s, 20s, 30s... Amps. Alternatively, the level 2 part of the forecasting system should predict GIC to within 10% of the observed value at least 95% of the time.

The industry representatives felt that the 10-Ampere granularity and 10% GIC (peak) prediction accuracy requirement may be unnecessarily strict. From the transmission system or generator operator viewpoint there is no large difference between, for example, GIC of 20 A and 30 A. As was discussed above, it is more useful to capture peak GIC in three broader categories of small/medium/large. The boundaries for these categories are operator dependent. For one operator that participated the requirements discussions, "small" is an event having observed GIC of 30-90 amperes in the transformer neutral, 90-250 A "medium" and above 250 A "large."

Based on the industry feedback, the requirement may be restated as:

Requirement: Level 2 part of the forecasting system should be able to predict event <u>peak GIC</u> with a 3-level granularity of small/medium/large. While the boundaries between three categories are operator dependent, "small" could be 10-50 A in the transformer neutral, "medium" 50-100 A and "large" > 100 A. In this example, "all clear" would be an event with peak GIC < 10 A. The level 2 part of the forecasting system should predict the peak GIC within the correct category at least 95% of the time.

It should also be mentioned that some users felt the prediction of the geoelectric field would be more advantageous for their application.

Requirement: Level 2 part of the forecasting system should be able to predict significant events. A significant event is defined by an enhancement of GIC that equals or exceeds 10 A. The minimally acceptable rate for correct predictions is 90%.

Based on the industry feedback, this requirement can be folded into the previous requirement about 3-level small/medium/large peak GIC predictions. "Large" would be equal to "significant" stated in this draft requirement. Capturing large events is especially important for the industry and definition for "large" is again operator dependent. However, the industry representatives felt that 10 A (transformer neutral) is too low to be considered as "large" or "significant." Based on the ongoing geomagnetic storm standards development where 15 A/phase is proposed as a threshold for more detailed transformer thermal assessment, it can be argued that 100 A (neutral, i.e. three phases combined) or larger peak GIC could be considered as a rule of a thumb for defining a "large" event.

Requirement: Level 2 part of the forecasting system should be able to provide accurate "all clear" announcement following a GIC event. "All clear" is understood here as no further significant enhancements at the defined threshold(s) are expected during the ongoing (or decaying) storm. "All clear" forecasts also mean that no new significant enhancement is expected within the level 2 lead time (15-45 minutes). The minimally acceptable rate for correct predictions of "all clear" is 90%.

All industry representatives agreed that the basic idea behind the requirement is appropriate. However, it was indicated that "all clear" that is valid only for the next 15-45 minutes is not very useful. In words of one industry representative: "All clear forecasts only predict for the next 45 minutes, it does not seem to have much value for operational decisions since we probably will not do any switching only good for 45 minutes. In addition, it somehow gives misleading signal that a GMD event is over, but actually it probably [is] not." Consequently, "all clear" predictions should be geomagnetic storm wide announcements about "exit" or "event termination" conditions indicating that no further elevated GIC activity is expected over the storm.

One user expressed a desire for a higher confidence level for all clear (99%).

Requirement: Level 2 part of the forecasting system should be able to predict the start and end times of significant events to within 4 hours, 90% of the time.

All industry representatives agreed that the requirement is appropriate.

Please indicate the relative importance of correct forecasts compared to false alarms for the Level 2 part of the forecasting system. What is the approximate ratio of the cost of taking protective action in response to a forecast of a significant event compared to the cost of not taking action when a significant event occurs unexpectedly?

The cost/benefit information is operator dependent. The derivation of detailed cost/benefit curves (as a function of event strength) is a very intricate analysis involving many layers of system impacts considerations and thus the cost/benefit information is typically not well quantified. See also *Pulkkinen et al.* (2010) for more discussion on this. However, the industry representatives indicated that there is some tolerance for false alarms of especially large events because the primary GIC concern is associated with major events. In words of one industry representative: "False alarms are OK, we just can't afford to miss the big one." False alarm rate should not be too high, however, because on practical level "if significant events are incorrectly predicted frequently, operators will start to ignore them" in words of another industry representative.

3.3 Other considerations

In this section the text in italic are the questions posed to the industry representatives and the text immediately below are the industry representative reactions on the questions.

How would you use the GIC forecasts in your operations?

In general, reliable forecasts would be used to initiate mitigation actions. The usage of forecast information and corresponding actions are varied and highly operator dependent. According to one industry representative, action based on reliable forecast could be:

"For example, staging the portable GIC monitor and turn all GSU coolers on is one. If the anticipated GIC is extreme, we may do preparations for taking a nuclear unit off-line and staff an Outage Control Center to manage the unit off-line and perform unrelated maintenance (for improved equipment reliability when unit is returned to service)."

In words of another industry representative:

"1) We can re-dispatch generation or increase spinning reserve. Every area will have a better balance of Generation/Load and we will reduce large power transfer across critical corridors. More generation means better reactive power support. We are better prepared to deal with contingencies. 2) We can cancel/postpone outages in the system. For example, we may have scheduled maintenance on a critical piece of equipment (a capacitor bank) that would be prudent to cancel. 3) Adjust the topology of the system. The flow of GIC is highly dependent on the configuration of the system (how are the lines connected, transformers, etc). It is possible to adjust the topology to reduce GIC flows in critical areas in the system. 4) Initiate forced cooling in transformers. Transformers typically have an automatic system that at certain load/temperature starts forced cooling (fans, pumps to circulate oil, etc). You can manually start forced cooling and lower the temperature of the transformer by a few degrees. NOTE: the rate of rise of temperature caused by GIC is going to be the same, however, you will start from a lower temperature. 5) Study in advance a set of "credible contingencies". We know where our critical locations with respect to GIC are. We can study a special set of contingencies in that area, using the prevailing system state, to determine our risk and exposure. 6) Situational awareness. The operator awareness on certain indicators around critical areas will be raised. We constantly monitor millions of alarms, equipment status, system parameters, etc. Knowing what to look for and where is vital for the operator."

According to one more industry representative, the forecasts could benefit in real terms as:

“

- Situational awareness and advance steps in safe posturing (station and fleet management level) and readiness preparations starting in advance of real time WARNINGS and ALERTS
- We may elect to immediately return transmission assets back into service that might be out for minor maintenance (and have the time to do so (very important here, as we would may not have time under real time conditions to back out of maintenance))
- Postpone switchyard maintenance
- Postpone our 30-day nuclear Emergency Diesel surveillances (where we tie to the grid for a one hour test)
- Dedicate resources to prepare for down power or removing the unit from service until the storm passes (not that we would do that, but that we'd be better prepared by reviewing our nuclear down power procedures)
- Improvement in communications with our grid operators in readiness preparations
- Better Fleet Communications update: I perform the function for our whole Fleet (Nuclear & Non-Nuclear Assets) using your 3-day forecasts, WATCHES, etc., (and send out broadcast emails - see example attached) and the stations appreciate it because they ensure they dust off the Solar GMD procedure and get resources ready. Having this kind of notice in the future would ensure better execution of asset protection than if it came as a real time surprise.”

While it is clear that successful GIC forecasts would be used by the industry in a number of ways, it is emphasized that the usage is highly dependent on the reliability of the forecasts. Operators will not use non-validated and non-verified forecasts in their mitigation procedures. Consequently, verification & validation (V&V) of the forecasting system is an essential part of the process in making the system useful for the industry. It was indicated by the industry representatives that V&V using historical events is valuable means to provide confidence on the system’s performance. However, on practical level the best means for V&V is through real-time experience where forecast data are made available to the operators and confidence is gained through observing the performance of the system over a few storm events. Operators would check, for example, small/medium/large event forecast versus what was observed at specific locations and carry out observed versus predicted peak GIC comparisons within a few hour sliding windows.

Please provide any other possible requirements you think should be captured in this exercise.

The industry representatives provided no additional requirements.

4. Discussion

While we believe that the information provided in this document will provide a good requirements baseline for the development of GIC forecasting systems such as Solar Shield, the document should be considered as "living" since we expect the requirements to evolve over time. The scientific understanding about GIC and industry as well as federal regulatory awareness around the issue is evolving rapidly. As new information becomes available, it is expected that the end-user needs for GIC forecast information will evolve. Consequently, our Solar Shield team will review the document periodically over the lifetime of the extended Solar Shield project and make adjustments if new information becomes available. Recognizing that this report represents only the US view, we also strongly encourage amending this initial work with international industry perspectives when possible.

Based on the information provided in this document, we can sketch an ideal GIC forecasting system. The forecast system will have two different forecast windows: 1-2 days and 15-45 minutes. The system will provide location-specific peak GIC and/or geoelectric field magnitude estimates at three different categories: small, medium and large events. The boundaries of the categories are operator dependent but could be, for example, "small" 10-50 A, "medium" 50-100 A and "large" > 100 A. The system will communicate also the uncertainties associated with the estimates. System will give "all clear" after there is a good confidence that the storm and the corresponding GIC activity have subsided. "All clear" will be announced when the expected GIC fall below "minor" category, i.e. < 10 A in the example above. The system will be optimized to catch the large events, and a small number of false alarms of large events will be considered as lower priority. The reliability of the forecasting system will be demonstrated via operator monitoring of GIC predictions in real-time. Operators will gain confidence in the system by verifying that there is a good match between the observed and predicted GIC.

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Appendix: end-user requirements questionnaire

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GIC Forecasting System Requirements Questionnaire

NASA Goddard Space Flight Center (GSFC) Heliophysics Science Division-lead team that includes NOAA Space Weather Prediction Center, Electric Power Research Institute (EPRI) and Electric Research and Management, Inc. (ERM) participants has recently partnered with the Department of Homeland Security (DHS) to better understand the Geomagnetically Induced Current (GIC) impact on the electric power industry. NASA GSFC initially working with EPRI and ERM developed a Solar Shield system to predict the GICs. The present focus is to extended the Solar Shield system project (for a description of the "old" system, see http://science.nasa.gov/science-news/science-at-nasa/2010/26oct_solarshield/) to enhance the forecast capability. To do this, we also need better understanding of the user requirements. We have developed the following questionnaire to incorporate the user inputs and initiate a dialogue. The initial information gathering will be followed by a webinar that will allow more interactive discussions.

It is emphasized that the ultimate goal of the forecasting system development is to be able to provide timely and accurate information enabling operational decisions about proactive GIC mitigation actions. Please measure the questions below against this end goal and also indicate what other requirements are necessary to meet the goal.

The questionnaire is structured around our Solar Shield team's initial understanding of the GIC forecasting system requirements. The draft requirements also takes into account what, based on current and near future capabilities, can realistically be expected from any GIC forecasting system. We kindly ask you to comment on each draft requirement item and also to provide feedback about possibly missing items. Your comments could include "this requirement is appropriate and accurate", "this requirement is not necessary" or "this requirement needs to be refined as …" The information we receive from you will help define the research work on the forecasting system and help planning for transition to operations activities at the end of the project. You can contact Solar Shield PI A. Pulkkinen if you have any questions on this questionnaire.

* Required

Your name *

Your affiliation *

General forecasting system requirements

Requirement: The GIC forecasting system should be able to give advance warnings at two different levels: Level 1 warnings providing lead-time of 15-48 hours and Level 2 warnings providing lead-time of 15-45 minutes. Level 1 warnings are based on remote sensing information about solar activity whereas Level 2 warnings are based on in situ Lagrange point 1 observations.

Please provide comments on this requirement.

Requirement: The system should be able to predict the start time of the GIC activity. Start times are given separately for Level 1 and Level 2 forecasts.

Please provide comments on this requirement.

Requirement: The system should be able to predict the intensity of the GIC activity. Intensities are given separately for Level 1 and Level 2 forecasts.

Please provide comments on this requirement.

Requirement: The system should be able to indicate the geographic regions or locations affected by the GIC activity. Affected geographic regions are given separately for Level 1 and Level 2 forecasts.

Please provide comments on this requirement.

Requirement: The system should be able to predict the end of the GIC activity. End times are given separately for Level 1 and Level 2 forecasts.

Please provide comments on this requirement.

Requirement: The system should be able to give uncertainty of the prediction. Uncertainties are given separately for Level 1 and Level 2 forecasts.

Please provide comments on this requirement.

Requirement: The system should be able to give the prediction of the GIC activity in a form usable for the decision-making process associated with possible GIC mitigation actions.

Please provide comments on this requirement. If you agree with the requirement, please provide ideas about how the GIC information should be presented.

Level 2 (15-45 min. lead-time) forecasting system-specific requirements

Requirement: Level 2 part of the foresting system should be able to predict GIC with 10 Amp granularity and accuracy. In another words, the Level 2 system should be able to predict if the GIC will be 10s, 20s, 30s... Amps. Alternatively, the level 2 part of the forecasting system should predict GIC to within 10% of the observed value at least 95% of the time.

Please provide comments on these two requirements. Comment if the requirement is too strict, appropriate or too loose. Would this requirement allow you to make proactive operational decisions?

Requirement: Level 2 part of the forecasting system should be able to predict significant events. A significant event is defined by an enhancement of GIC that equals or exceeds 10 A. The minimally acceptable rate for correct predictions is 90%.

Please provide comments on this requirement. Comment if the requirement is too strict, appropriate or too loose. Is 10 A the correct threshold? Are there additional thresholds that are important? Would this requirement allow you to make proactive operational decisions?

Requirement: Level 2 part of the forecasting system should be able to provide accurate "all clear" announcement following a GIC event. "All clear" is understood here as no further significant enhancements at the defined threshold(s) are expected during the ongoing (or decaying) storm. "All clear" forecasts also mean that no new significant enhancement is expected within the level 2 lead time (15-45 minutes). The minimally acceptable rate for correct predictions of "all clear" is 90%.

Comment if the requirement is too strict, appropriate or too loose. Would this requirement allow you to make proactive operational decisions?

Requirement: Level 2 part of the forecasting system should be able to predict the start and end times of significant events to within 4 hours, 90% of the time.

Please provide comments on this requirement. Comment if the requirement is too strict, appropriate or too loose. Would this requirement allow you to make proactive operational decisions?

Please indicate the relative importance of correct forecasts compared to false alarms for the Level 2 part of the forecasting system. What is the approximate ratio of the cost of taking protective

action in response to a forecast of a significant event compared to the cost of not taking action when a significant event occurs unexpectedly?

Other possible general requirements for the GIC forecasting system

How would you use the GIC forecasts in your operations?

We understand that this depends on the timeliness, accuracy etc of the forecasts. However, it would be very useful to have a general idea about how the forecasts would be used by the industry in their decision making.

Please provide any other possible requirements you think should be captured in this exercise.

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